Hydrology

Background and Objectives

The purpose of the Hydrology module is to characterize the hydrologic regime of the watershed and assess its susceptibility to alterations from land and water use practices. When hydrologic processes are altered, the stream system responds by changing physical parameters, such as channel configuration. These changes may in turn impact chemical parameters and ultimately the aquatic ecosystem.

The degree to which hydrologic processes are affected by land and water use depends on the location, extent, timing, and type of activity. Watershed activities can potentially cause changes in the magnitude and timing of both peak flows and low flows. Some activities (e.g., temporary roads, low levels of timber harvest, and seasonal irrigation withdrawals) cause short-lived alterations to the hydrologic regime, while other activities (e.g., dams, urbanization, and channelization) cause fairly permanent changes in the watershed and thus to the hydrologic regime.

Hydrologic processes are complex, involving myriad interactions that are difficult to quantify. The list of hydrologic concerns generated in the Scoping process will provide direction to the assessment. In addition, seven critical questions are posed to help focus the assessment. The Hydrology Module Reference Table indicates the critical questions that may be addressed in the initial Level 1 assessment and options for further Level 2 analyses. This module provides detailed steps for Level 1 assessment and a general discussion of options for Level 2 assessment.

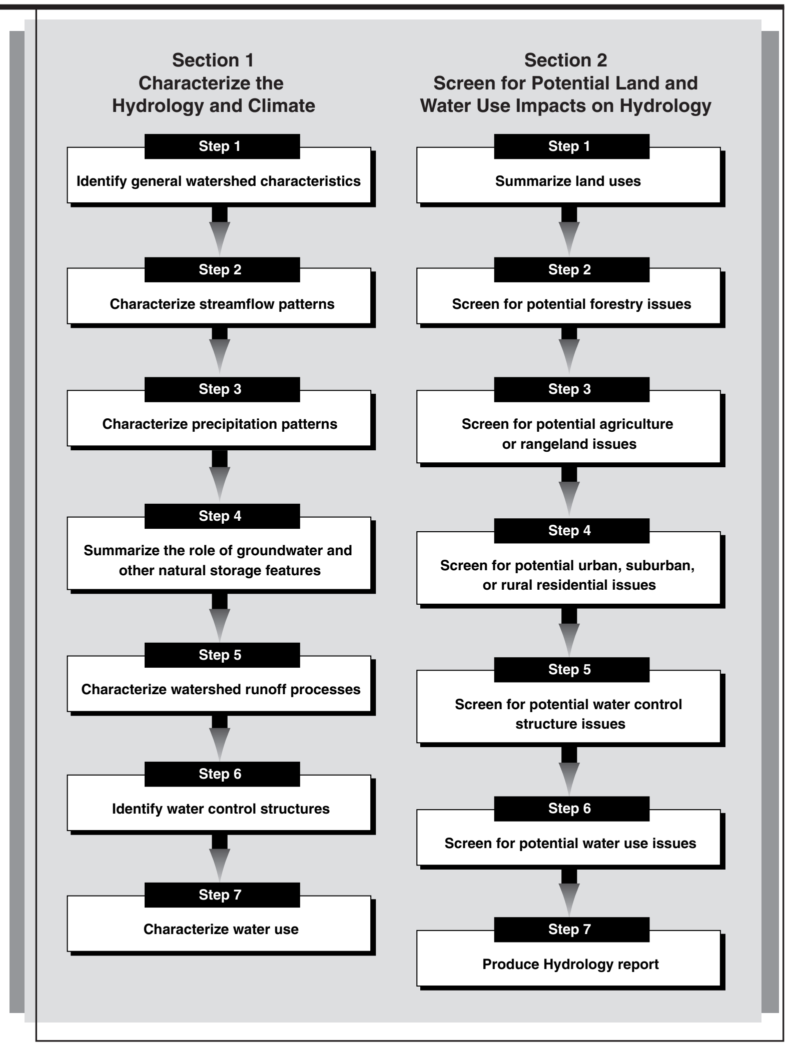
Level 1 assessment characterizes the hydrology and climate of the watershed and screens for potential land and water use impacts. Characterization refers to gathering and organizing existing data into a qualitative description of conditions. The Level 1 assessment does not produce definitive or quantitative results; however, the screening does provide justification and focus for future Level 2 assessment.

Hydrology Module Reference Table

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
H1: What is the seasonal variability in streamflow?	• Representative streamflow records	• Tabulate and graph flow data • Summarize peak and low flow patterns	• Ungaged streamflow analysis • Frequency analysis (flood and low flow) • Flow duration curves
H2: What is the climatic setting of the watershed?	• Representative climate data • Topographic maps • Watershed characteristics	• Tabulate and graph precipitation data • Summarize storm patterns	• Storm analysis • Trend analysis • Double mass analysis
H3: What are the roles of groundwater and natural storage features in the watershed?	• Hydrogeologic maps and aquifer descriptions • Vegetation module maps	• Locate storage features in the watershed: snowpack, lakes, wetlands/swamps • Define groundwater areas	• Hydrograph separation techniques • Characterize surficial aquifers
H4: What are the active runoff generating processes?	• Topographic maps • Watershed characteristics	• Describe runoff processes	• Storm analysis • Watershed hydrologic models
H5: What water control structures are present in the watershed?	• Historical Conditions module timeline • Aerial photos • Topographic maps	• Locate reservoirs, lakes, diversions, dams • Characterize extent of draining and ditching and other hydromodifications	• Deregulate streamflow records • Reservoir routing models • Reservoir operation models • Watershed hydrologic models
H6: For which beneficial uses is water primarily used in the watershed, and are surface water or groundwater withdrawals prominent?	• Land use map • Topographic maps • Aerial photos	• Identify types of water uses and typical withdrawals in the watershed • Determine periods of high water demand	• Water rights analysis • Consumptive use estimates • Water balance calculations • Network/allocation models • 3D groundwater models
H7: What are the potential land use impacts to hydrologic processes in the watershed?	• Percentage of watershed occupied by each land use • Vegetation coverage • Hydrologic soil information • Percentage impervious area	• Screen for potential impacts	• Empirical relationships • Regional relationships and models • Storm hydrograph techniques • Continuous hydrologic models

Level 1 Assessment

Step Chart



Data Requirements

- Map of the watershed showing topography and stream network. USGS or equivalent topographic quadrangle maps at a 1:24,000 scale are adequate.
- Stream network classification map (if available). Many states have adopted regulatory categorizations pertinent to stream order (e.g., stream order, water type, stream class). If state classification maps are available, they can be useful to cross-reference with the Channel module and Aquatic Life module analysts.
- Land use map with sub-basins delineated (from Scoping).
- Mean annual precipitation map.
- USGS hydrologic atlases and groundwater atlases.
- Streamflow data.
- Soil survey maps.
- Surficial geology maps (if available).
- Hydrogeologic maps describing aquifer conditions (if available).
- Aerial photos or orthophotos (as necessary).
- Other relevant published or unpublished documents (city, county, tribal, state, or federal agency or private consultant reports) with watershed information.

Data Sources

The USGS is the best source of water-related information in the United States. The USGS collects streamflow, surface water quality, groundwater level, and groundwater quality data. It publishes water resources data by state and water year, water resources investigation reports, open-file reports, water resources bulletins, professional papers, and hydrologic investigations atlases. USGS publications are available in many libraries or they can be ordered through the U.S. Government Printing Office. The information number for the USGS is **1-800-426-9000.**

Hydrologic data

Current and historical streamflow data can be downloaded from the home pages of the USGS district water resource offices. Streamflow data are also available commercially on CD-ROM. Published resources include the following:

- USGS. *National Water Summaries: Hydrologic Events and Surface-Water Resources*. These documents contain nationwide and state information on water resources, including generalized maps of surface water runoff, water-related issues, groundwater quantity and quality, and wetland locations.
- U.S. Water Resources Council (1978). *The Nation's Water Resources*. Although dated, this is still the most recent and comprehensive nationwide assessment of the United States' water problems.
- USGS publishes open file reports containing regional flood equations (e.g., USGS 1979).

Climatic data

The National Weather Service and its data repository, the National Climate Data Center, have websites that provide easy access to useful climate information (**http://www.nws.noaa.gov** and **http://www.ncdc.noaa.gov**). Climate data are also available commercially on CD-ROM. There are six regional climate centers (Western Regional, High Plains, Southern, Midwestern, Southeast, and Northeast), each of which can provide information on how and where to download climate data and assist in identifying an appropriate climate station. Some states have designated state climatologists who are a valuable resource. Published resources include the following:

- NOAA National Weather Service. The Climatic Record of the United States by State. These documents contain daily, monthly, and annual climate information on precipitation, temperature, evaporation, degree days, and other climate data by weather station. NOAA also publishes a *Mean Annual Precipitation Map*.

- U.S. Weather Bureau Technical Paper 40, *Rainfall Frequency Atlas of the United States* provides information on 24-hour storms for the conterminous United States. Precipitation atlases for specific states (e.g., Miller et al. 1973) are also available.

Water use data

The USGS updates water use estimates every five years. Water use data can be obtained through the USGS water use icon on the EPA's Surf Your Watershed web site (**http://www.epa.gov/surf/**).

Groundwater resources data

- Hydrogeologic provinces. Heath (1984).
- *The Ground Water Atlas of the United States*, USGS Hydrologic Investigations Atlas, HA 730 A-N series. This atlas consists of 14 chapters that describe the groundwater resources of regional areas. A nationwide aquifer map is included along with descriptions of groundwater characteristics, flow directions, chemical composition, and water balance components such as runoff, precipitation, and evaporation. The text of this atlas is available online (**http://wwwcapp.er.usgs.gov/publicsdocs/gwa**).

Products

- Form H1. General watershed characteristics
- Form H2. Summary of hydrologic issues by sub-basin
- Map H1. Water control structures
- Hydrology report

Procedure

The primary objectives of the Hydrology assessment are as follows:

- To characterize the hydrologic regime of the watershed by summarizing the following:
  - Watershed characteristics.
  - Streamflow patterns.
  - Precipitation patterns.
  - Watershed storage and groundwater features.
  - Watershed runoff processes.

- To locate land uses (agriculture and rangeland, urban, forestry, mining, etc.), water uses, and water control structures (dams, dikes, diversion, etc.) in the watershed.
- To screen for potential impacts on hydrology from land and water use.

The Level 1 evaluation procedure is separated into two sections. The steps in Section 1 characterize the hydrologic and climatic setting of the watershed. The steps in Section 2 direct the user to screen for potential hydrologic issues associated with the land and water uses present in the watershed.

The hydrologic evaluation may need to be carried out at the sub-basin level. This will require adjusting streamflow and precipitation records to reflect conditions in each sub-basin.

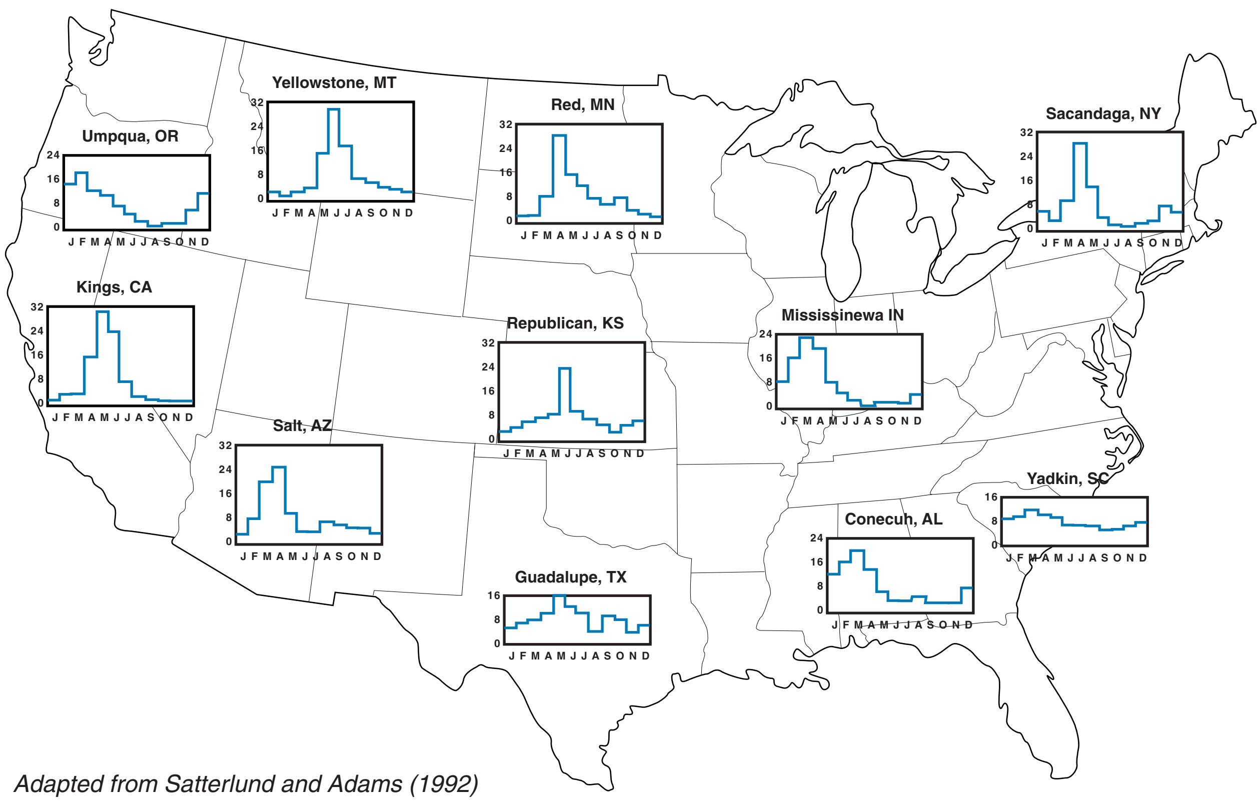
Section 1. Characterize the Hydrology and Climate

The geographic layout of the United States encompasses several diverse physiographic and climatic zones, causing the amount of runoff and its distribution throughout the year to vary considerably from region to region (Figure 1). Watersheds differ in both the ability to produce flood flows and the ability to sustain flows during the dry periods.

Most streams do not produce uniform flow over the year. Instead, streams typically exhibit patterns in flow reflective of individual storms, months, and seasons (Figure 1). The seasonal pattern of streamflow in a watershed is largely governed by the climatic inputs to that watershed (the amount, form, and timing of precipitation) offset by losses from the watershed (the amount and timing of evapotranspiration losses and snowmelt). The geologic characteristics of the watershed also heavily influence the streamflow regime, as demonstrated by the marked difference between the hydrographs compared in Figure 2. (A graphical plot of streamflow data over time is called a hydrograph.) Finally, physical characteristics—such as the size of a river system, drainage shape, topography, type of vegetation or ground cover, and amount of natural water storage—all influence the specific runoff pattern of a given stream.

While flooding is common in each of the 50 states, the type and frequency of peak flow events differ dramatically both within and among states. Floods can stem from many factors, including heavy rainfall, rapid snowmelt, rain-on-snow, and thunderstorms, as well as more dramatic ice jam breakups, channel avulsions, and dam or levee failures. In coastal areas, hurricanes, winter storms, tsunamis, and rising sea levels can generate floods.

Figure 1. Average monthly runoff (as a percentage of annual flow) for selected gages in the United States

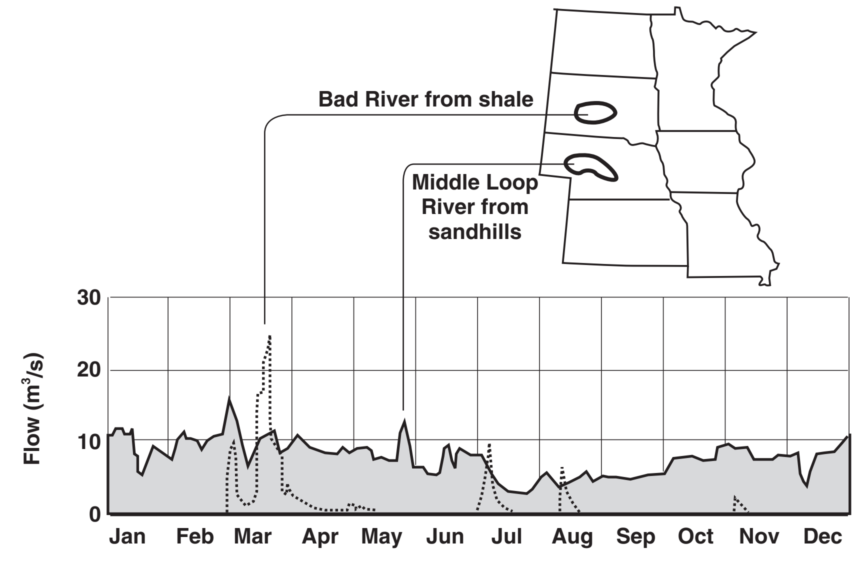


Adapted from Satterlund and Adams (1992)

Baseflows or low flow regimes also vary from stream to stream. Intermittent streams go dry for a period of time every year, while other streams do not experience much fluctuation from high flow to low flow periods (see example for Yadkin, South Carolina, in Figure 1). Many factors influence the amount of water found in streams during the low flow period:

- Rate of snowmelt and glacial melt.
- Geologic characteristics.
- Outflow from lakes and reservoirs.
- Rate of evapotranspiration from soils and vegetation.
- Effects of upstream water withdrawals and irrigation return flows.

Figure 2. Geology modifies streamflow regime from two watersheds with similar climates



Adapted from Satterlund and Adams (1992)

Several of the influencing factors may only be important in certain regions. For instance, assessing the importance of glacial melt in sustaining late summer/early fall low flows will be required for some watersheds located along the Pacific Northwest's Cascade Mountain range and in Alaska, as well as a few watersheds in the Northern Rocky Mountain and Canadian Rocky Mountain ranges. Wetlands, while present throughout the nation, are most prevalent along the southern seaboard, gulf coast, and lower Mississippi River and in the glacial terrain of the north-central United States.

Each region and even each watershed will have unique issues. This section will focus on summarizing physical watershed characteristics and collecting available streamflow and climate data in order to discern the hydrologic issues. The typical distribution of runoff over the course of the year as well as the dominant peak flow and low flow issues in the watershed will be investigated.

Step 1. Identify general watershed characteristics

Using the watershed base map generated in the Scoping process, review and clearly delineate the boundaries of each identified sub-basin. Form H1 can be used to compile and organize watershed-specific hydrologic information. For each sub-basin, identify basic watershed features such as drainage area, topographic relief (e.g., minimum and maximum elevations), geology, drainage pattern, stream gradient, and mean annual precipitation. If GIS support is available, some of the information can be calculated using the computer. Otherwise, use USGS topographic maps and a map of mean annual precipitation (from NOAA or a state agency) to estimate values for each characteristic.

Step 2. Characterize streamflow patterns

Identify gages

Identify any streamflow gages in or near the watershed of interest and develop a table summarizing station information such as the station name, location, elevation, and period of record.

The USGS has been operating streamflow stations across the country since the turn of the century. In some regions, stream gages are numerous and have long periods of record, while in other regions (e.g., west of the Mississippi), there are fewer gages and they have shorter periods of record. The following are factors to consider in finding representative streamflow data:

- Where gages are numerous, the task will be to select the most useable and representative gages.
- Watershed size will be an important decision criterion, as will length of record; longer records offer more insight into the variability of streamflow. To obtain representative data for a watershed, the gage records should cover at least ten years.
- The gaging station does not need to be currently in operation; historical data still offer a glimpse into how a watershed responds to storm inputs (precipitation, temperature, wind, etc.).
- Gage records should represent unregulated streamflow (where no reservoirs or diversions exist above the gaging station). Gages downstream of a reservoir or even a millpond will not record natural peak flows but will reflect streamflow modified by the structure (Box 1).

Box 1. Regulated watersheds

For watersheds with dams, large-scale diversions, or other flow-altering activities; streamflow data remarks will need to be reviewed in detail prior to use. The first task will be to determine the unregulated portion of the record, prior to completion of the flow-altering activity. Summary statistics and hydrographs developed from the unregulated portion of the streamflow record can offer an indication of the pre-alteration flow regimes. Techniques for deregulating the post-alteration record can be undertaken as a Level 2 analysis.

The USGS information office nearest the watershed can help locate an appropriate gage or gages. If a stream gage is not located in the watershed, obtain records for a nearby stream gage draining a hydrologically similar watershed. Gages located in adjacent watersheds will not necessarily be representative of conditions in the watershed being assessed. Therefore, it is important to assess hydrologic similarity by using the basic criteria listed in Box 2 prior to selecting a surrogate gage. When hydrologic similarity criteria are not met, ungaged streamflow analysis may need to be conducted (Box 3).

Box 2. Criteria for assessing hydrologic similarity of two watersheds

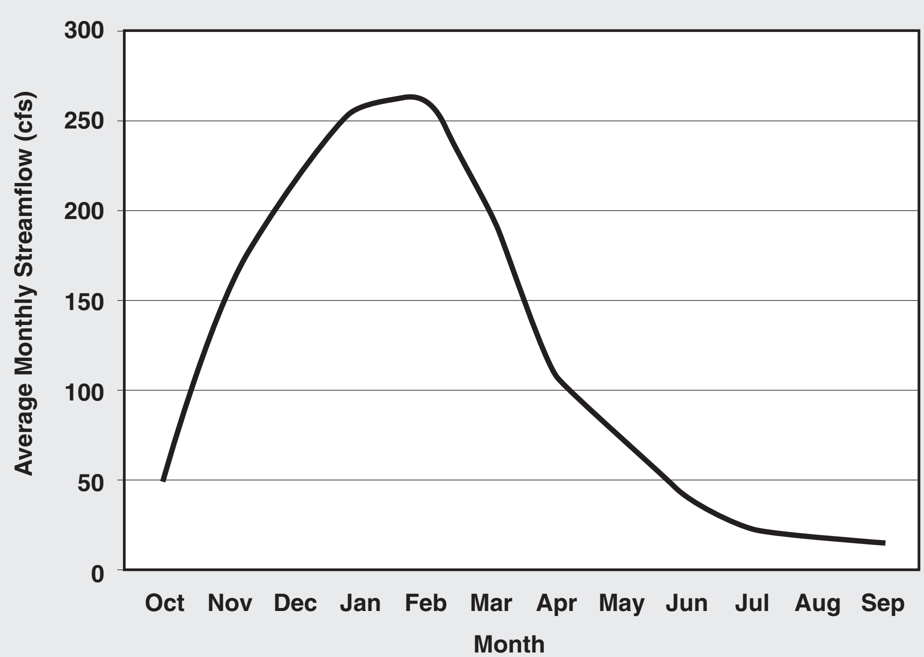
- Watershed drainage areas within the same order of magnitude
- Similar mean watershed elevation above the gage
- Similar precipitation and weather patterns
- Similar geology and topography
- No or insignificant out-of-stream diversions

Robison (1991)

Generate hydrographs

Obtain the mean monthly streamflow for the period of record for each of the selected streamflow stations. Generate a typical annual hydrograph (Figure 3) for each station. The shape of the hydrograph provides an identifying characteristic of a watershed. If more than one

Figure 3. A typical annual hydrograph for winter storm-driven regime



Box 3. Estimating streamflow in ungaged watersheds

For watersheds where either no or minimal streamflow data are available, numerous methods exist to estimate streamflow. Only the methods that do not require extensive data or modeling are presented here.

Flood regression equations
The USGS has developed regional flood regression equations for many areas of the United States. These reports are typically published by state and entitled Magnitude and Frequency of Floods. The equations can be used to estimate different flood events, such as the 2-year flood, 25-year flood, etc., based on watershed area, precipitation, and land cover. Inquire at the nearest USGS office about appropriate regional equations.

Area-precipitation method
In humid areas of similar geology, mean annual flow is closely related to drainage area and mean annual precipitation. Mean flows may be estimated if 1) flow records from nearby watersheds are available; 2) an isohyetal map is available (isohyets are contour lines of equal precipitation); and 3) the geology of the area is relatively homogeneous.

Unit runoff method
Streamflow from a hydrologically similar watershed can be converted into runoff per unit area (e.g., cubic feet per square mile) to estimate some of the streamflow statistics for the ungaged watershed. Please note that these statistics are general estimates to be used to assess relative magnitudes rather than absolute values. If there are any miscellaneous streamflow measurements made in the watershed, these data can be compared to a gaged station to establish a predictive relationship (i.e., regression analysis).

Surface water runoff maps
Use the USGS generalized maps of surface water runoff.

stream gaging station exists in the watershed, compare the hydrographs from each. Consider the following questions:

- In which month or months does the majority of runoff occur?
- When do low flows occur?
- If comparing hydrographs, do they generally have the same shape, or does the timing of runoff vary?
- Are flow patterns seasonally predictive?
- Do streams show great fluctuations in flow within seasons?

Optional Task: Where representative daily streamflow data are available, develop the average daily hydrograph using the entire period of record. Compare daily flows over a few years.

Aquatic Life

Flow variability is an important factor to aquatic ecosystems. The information collected in this step may be useful to the Aquatic Life analyst. For example, the hydrographs can be compared to the aquatic species' stream flow requirements to illustrate the timing of streamflow in relation to the needs of aquatic life.

Summarize peak flow data

Obtain and graph the annual peak flow data associated with the selected streamflow gages (Box 4). Enter the data into a table (similar to Figure 4) that tracks the magnitude of annual peak flows in cubic feet per second (cfs) and the date of each peak flow. Consider the following questions:

Aquatic Life

- In which month or months do the majority of the annual peak flows occur?
- Do extreme high flows occur during critical periods for aquatic life?
- Have high flows influenced habitat conditions?

Box 4. Annual peak flows and water years

For each station, a record of annual peak flows should be available (see the "Data Sources" section). Annual peak flows represent the highest recorded discharge for that station for a given water year. The water year differs slightly from the calendar year. Water year is defined as the 12-month period starting on October 1 and ending on September 30. October 1, 1999, through September 30, 2000, would be referred to as water year 2000.

Summarize minimum flow data

Obtain and graph the annual minimum flow data associated with the selected streamflow gages. These data are available from numerous data sources. For instance, the USGS Water Resources Data series, published by state for each water year, provides summary statistics for each station currently in operation. Among the statistics, lowest mean daily flow can be found along with the annual seven-day minimum (lowest mean streamflow for seven consecutive days in a water year; see also Box 5). Report the magnitude of low flows and their dates of occurrence in a table similar to the

Box 5. Low flow frequency

Low flow statistics often include reference to the seven-day ten-year low flow ($7Q_{10}$). The $7Q_{10}$ is a statistic that represents the lowest mean discharge for seven consecutive days that has a probability of occurring once in ten years.

Figure 4. Sample table format for summarizing annual peak flow data

Annual peak flows for each water year of record

Station name: | Station number:
Drainage area: | Period of record:

Water year *	Peak flow amount (cfs)	Date of peak flow	Season of peak flow

** October 1 - September 30*

peak flow data table (Figure 4). In addition, record the minimum discharge for the period of record of the gage. Consider the following questions:

- In which month or months do the annual minimum flows typically occur?
- Do extreme low flows occur during critical periods for aquatic life?

Aquatic Life ▶

Step 3. Characterize precipitation patterns

Collect precipitation information

Obtain the NOAA mean annual precipitation map. Identify the climate stations nearest to your watershed and develop a table summarizing station information, such as station name, location, elevation, and period of record.

Summarize precipitation information

Describe the range and variability of precipitation from the mouth to the headwaters of the watershed and among the sub-basins. In addition, obtain the average monthly precipitation for the period of record and graph the annual distribution of precipitation. This graph of the rate of rainfall over time is called a hyetograph. Obtain and graph the annual maximum 24-hour precipitation. Consider the following questions:

- In which month or months does the majority of precipitation occur?
- When are the dry seasons?

- In which month and year does the largest annual maximum 24-hour precipitation event occur?
- Is this the same storm that produced one of the largest peak flows?
- In what month do most of the maximum 24-hour precipitation events occur?

Examine trends in data

If the period of record for the streamflow station and climate station overlap, examine the pattern that has occurred for peak flows and precipitation over time. Consider the following questions:

- Are annual peak flows consistently increasing or decreasing over a period of the record?
- Does a cyclical wet and dry pattern emerge in which short periods of lower peaks are interspersed with periods of higher peaks?

Historical Conditions

If some pattern seems apparent, then the next step is to discern whether the pattern mimics the climatic pattern. If there is a trend in the peak flow graph that is not apparent in the precipitation graph, then further study may be warranted. Keep this point in mind when proceeding with the hydrologic screening tasks. Note the year in which the trend in peak flows becomes apparent and the year in which it stops and try to identify major watershed changes that might have occurred coincidentally. Also be sure to review the streamflow and climate station histories to check for changes in gage locations. Check the Historical Conditions module timeline for input on watershed changes.

Step 4. Summarize the role of groundwater and other natural water storage features

Natural water storage features play a role in the runoff response of the watershed. In fact, hydrologic regimes in some regions are dominated by their storage components. "Storage-based"systems or subsurface-dominated flow regimes typically release water slowly over long periods of time. For instance, in the pine flatwoods of Florida, surface runoff occurs only when the groundwater table intersects the soil surface. Conversely, most rangelands, absent dense vegetation, offer little water storage. Surface runoff is the most common form of conveyance as evidenced by numerous rills and ephemeral channels.

Almost all streams interact with groundwater to some extent. In fact, groundwater discharge to streams (termed baseflow) often accounts for 50 percent or more of the average annual streamflow. The proportion of stream water that is derived from groundwater inflow, however, can vary considerably across physiographic and climatic settings. Streams can interact with groundwater in one of three ways:

1. Streams gain surface water from groundwater inflow.
2. Streams lose water to groundwater by outflow through the streambed.
3. Streams do both, gaining at some times or in some reaches and losing at other times or in other reaches.

Groundwater boundaries in many instances do not coincide with watershed boundaries; groundwater/surface water interactions are largely controlled by the geologic setting (Box 6). As an example of the effect that geology can have on the groundwater contribution to streamflow, Winter et al. (1999) compared the Forest River watershed in North Dakota with the Sturgeon River watershed in Michigan. The Forest River watershed is underlain by poorly permeable silt and clay deposits, which limit the contributions of groundwater to streamflow to around 14 percent of average annual flow. By contrast, the Sturgeon River watershed is dominated by highly permeable sands and gravels, causing the groundwater component of streamflow to be large, approximately 90 percent of its average annual flow.

Box 6. Hydrologically closed systems

Watersheds located in the glacial and dune terrain (the prairie-pothole region) of the north-central United States are characterized by hills and depressions with many lakes and wetlands. While streams drain portions of this terrain, typically they do not form a large drainage network, and stream outlets are often absent, indicating a "closed" system. Movement of water through this terrain is controlled primarily by exchange of water with the atmosphere (through precipitation and evapotranspiration) and with the ground water.

Erosion

Antecedent precipitation conditions also influence groundwater/streamflow interactions. During storms, a rising water level in the stream channel typically reverses the direction of groundwater flow, causing storage of water in the floodplain and recharge of adjacent aquifers. As the stream recedes, the stored groundwater is released slowly back to the stream.

Vegetation

Inventory water storage features

Locate and describe surficial water storage features in the watershed such as lakes, ponds, wetlands, and swamps. In some regions, the USGS has compiled descriptive watershed information for each streamflow gaging station (Williams et al. 1985). The EPA Surf

Your Watershed web page (**http://www.epa.gov/surf/**) has information on the number of lakes in the watershed, as well as the name, description of rock types, and square miles of coverage for each underlying aquifer. Confer with the Vegetation analyst to obtain the vegetation map documenting the extent of wetlands identified on the NWI maps and through aerial photo interpretation. If information is not readily available, storage features can be identified on topographic maps and aerial photographs.

Summarize snow data

If snow accumulates in the watershed, identify snow data collection stations in or near the watershed. The NRCS collects snowpack depth and snow-water equivalent data at stations in many regions. Contact the local NRCS office to determine whether snow stations are actively monitored in or near the watershed. Also, check with the USFS for snow data. Determine in which sub-basins snow accumulates and, if possible, estimate the snow pack depth.

Identify the presence of glaciers in the watershed. Glacial streams, primarily during low flows, will exhibit characteristics different from those for neighboring streams that are fed by snowmelt, lakes, and groundwater.

Summarize groundwater resources

Use available hydrogeologic resources, such as existing reports, maps, and aquifer descriptions, to summarize the knowledge of groundwater issues by sub-basin. The USGS Groundwater Atlas provides aquifer descriptions for most regions. Locate areas of productive groundwater discharge in the watershed (e.g., well fields, springs) and also potential areas of groundwater recharge (e.g., karst terrain; Box 7).

Over the past decade, as the joint management of groundwater and surface water resources has come to center stage, investigators have focused on characterizing the interactions. If the watershed is in an area with a recently completed regional-scale

Box 7. Karst terrain

Karst terrain refers to areas of highly disrupted surface water drainage systems due to the dissolution of underlying bedrock (typically limestone and dolomite). Solution openings, rock openings, and sinkholes intersect the surface, providing connection to the underground drainage network. Precipitation onto areas where karst terrain outcrops at the land surface tends to infiltrate quickly. Even large streams can run dry as they recharge the groundwater directly through sinkholes and solution cavities. This direct link also leaves groundwater resources very susceptible to pollution.

USGS studies (Brown and Patton 1995) found that streams traversing the karst terrain associated with the Edwards Aquifer in south-central Texas can lose considerable amounts of water. Yet, karst aquifers can also produce ample groundwater discharge. For example, springs near the margin of the Edwards Aquifer provide a continuous source of water for streams to the south.

North-central Florida provides an example of a mantled karst region with numerous sinkhole lakes. Many lakes in this region form as unconsolidated surficial deposits slump into sinkholes in the underlying highly soluble limestone of the Upper Floridian Aquifer.

baseflow study (Box 8), use the report to help define the role that groundwater plays in maintaining the streamflow.

Box 8. Baseflow studies

Recently completed baseflow studies are available for several regions in the country:

- Washington State, selected rivers and streams (Sinclair and Pitz 1999).
- The Great Lake area (Holtschlag and Nicolas 1998).
- The Chesapeake Bay area (Bachman 1997; Langland et al. 1995).
- The Appalachia region (Rutledge and Mesko 1996).
- The Central Savannah River watershed (Atkins et al. 1996).
- Pennsylvania (White and Sloto 1990).
- Tennessee (Hoos 1990).

Step 5. Characterize watershed runoff processes

The purpose of this step is to identify the relative importance of the runoff pathways (surface and subsurface) within the watershed. Using the information gathered in Steps 2 through 4, summarize the interaction among streamflow, precipitation inputs, groundwater, and storage components. Discuss, to the extent possible, the mechanisms by which runoff is generated. More than one runoff process can be active in a watershed, and often a predictable pattern will emerge (Box 9).

Box 9. Example runoff descriptions

- In forested watersheds draining deep soils in the Sierra Nevada Mountains, winter snow accumulation and spring snowmelt are the primary influences on the shape of the annual hydrograph. However, other hydrologic processes are also active. Groundwater release sustains streamflow relatively well into the summer, and all the more extreme peak flow events have resulted from mid-winter rain-on-snow events. Rain-on-snow events have typically generated peak flows up to five times greater than spring snowmelt peak flows.

- Some watersheds in the unvegetated shallow cirques of the Sierra Nevada Mountain alpine zone are snowmelt-dominated. Groundwater may contribute only a small portion of the total annual amounts of surface water; however, the groundwater inputs are the primary source of water for 8 to 9 months of the year.

As a general rule, overland flow pathways are dominant in arid areas and on paved urban areas or disturbed landscapes where infiltration capacity is often limited. Subsurface flow is more prevalent in humid regions with dense vegetation and deep, permeable soils. Where subsurface flow is a dominant contributor to storm runoff, the percentage of precipitation that reaches the stream during the storm is low; most of the rain is stored in the soil and groundwater, then released slowly.

Further distinction can be made regarding the influence of climate on runoff. In rainfall– or rain-on-snow–dominated hydrologic regimes, annual maximum precipitation events often occur at the same time of year as the annual peak flows. By contrast, in areas with a snowmelt-dominated regime, maximum precipitation events do not yield the largest floods; instead, spring melting of the accumulated winter precipitation (stored in the snowpack) generates peak flows. Watersheds with extensive wetland systems and other forms of storage will also show streamflow desynchronized from the precipitation inputs. In arid regions, intermittent streams often yield flash floods in response to high intensity rainstorms. The intensity of rainfall in these areas can be a more important factor in determining runoff than the total amount of rainfall. In the Great Plains region, thunderstorms provide more than half of the precipitation during the growing season (Maidment 1992).

Step 6. Identify water control structures

Locate on a map the water control structures in the watershed. Man-made structures and storage facilities such as water supply reservoirs, flood control reservoirs, and even abandoned dams (millponds) impact the streamflow downstream of the impoundment (Box 10). Information on the operation and physical attributes of such structures will be instrumental in any future Level 2 analyses.

Box 10. Hydrologic impacts of reservoirs

In 1963, Glen Canyon Dam began to store water, and Lake Powell reservoir was created along the Colorado River. Since then, the Colorado River downstream of the dam has not experienced its natural seasonal floods. Snowmelt produced pre-dam flood flows on the Colorado on the order of 2,400 m^3/s. Since 1963, the controlled releases from the Glen Canyon Dam have generally been maintained below 500 m^3/s. In addition to modifying the streamflow, dams impede the transport of sediment downstream by trapping it behind the dam (Poff et al. 1997).

Channel

Identify and map areas with channel modifications. Extensive levees, diking, or bank armoring can disconnect the channel from its floodplain, which in turn can impact the hydrologic function of the watershed. Confer with the Channel analyst to determine the extent of channel modification.

Step 7. Characterize water use

Water use, through diversions of surface water or withdrawals of groundwater from wells, reduces streamflow, potentially resulting in a negative impact on biological resources. Water use is generally categorized by beneficial use designations, such as municipal water supply, industrial water supply, irrigated agriculture, domestic water supply, fish and wildlife, recreation, and federal reserved rights.

Identify the types of beneficial water uses in the watershed and summarize them in a table. If overuse of either surface water or groundwater was identified as a concern during Scoping,locate areas of concern in the watershed. For instance, several areas in the country have pumped groundwater resources excessively, to the extent that the land surface is subsiding.

Water Quality

Make generalizations about the typical schedules of withdrawals for each beneficial use. For instance, withdrawals for irrigation may only be operated for a few months of each year, while withdrawals for water supply are typically year round. Characterize the surface water withdrawals separately from the groundwater withdrawals. Determine, if possible, how much of the water use is consumptive (Box 11) and the extent of imports of water from or exports of water to other watersheds (interwatershed transfers).

Box 11. Consumptive water use

Consumptive use is the quantity of water absorbed by a crop and transpired or used directly in the building of plant tissue together with the water evaporated from the cropped area.

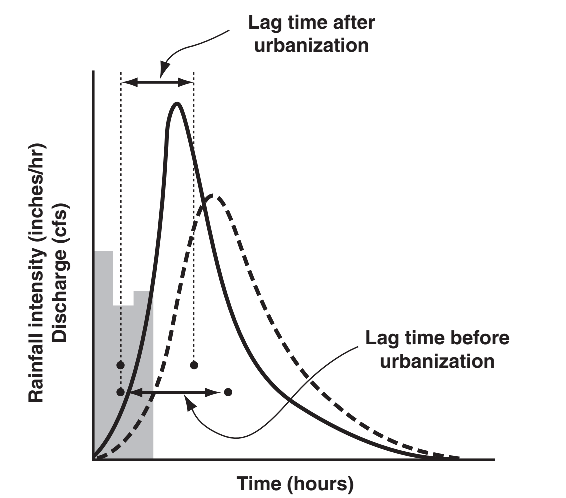
Section 2. Screen for Potential Land and Water Use Impacts on Hydrology

The screening process is designed to focus future analyses by identifying land and water use activities in the watershed that are potentially problematic. Land use practices and structural features, as well as water use, can modify the hydrologic regime of a watershed by altering one or more of the following:

- Amount of water available for runoff.
- Flow available in the channel.
- Routing of water to the streams.
- Lag time (delay between rainfall and peak streamflow; Figure 5).
- Travel distance to the stream.

Each activity has its own array of potential impacts to the hydrologic resources (Table 1). Those activities that affect the rate of infiltration or the ability of the soil surface to store water are typically most influential.   For instance, impervious surfaces associated

Figure 5. Hypothetical hydrographs demonstrating changes between pre-urbanization (dotted curve) and post-urbanization (solid curve) runoff



Adapted from Leopold (1968)

with urbanization inhibit infiltration, causing rain to run off more quickly, as shown in Figures 5 and 6 and described in Box 12.

The screening steps will draw on the information gathered in the characterization section and offer guidance for the analyst to determine which potential land or water use issues warrant further investigation. For each sub-basin, enter a "Yes" or "No" under each use category on Form H2. A "Yes" on Form H2 indicates that a potential for hydrologic impacts exists for the use in the sub-basin. A "No" indicates that either the use does not occur in the sub-basin or that the impact is projected to be minimal. In addition, the last column on Form H2 encourages comments on the rationale behind each screening response.

Box 12. Example of urbanization impacts

> Urbanization causes the peak flow (highest point on the curve) to increase and to occur sooner (the lag time has decreased), as shown in Figure 5. The same concepts are shown in Figure 6, where two streams respond differently to the same rainstorm: one stream drains a forested watershed, and the other drains an urbanized watershed.

Keep in mind that the work completed in this screening is not definitive. More detailed technical analyses are necessary to verify the presence of

Figure 6. A typical annual hydrograph based on mean monthly flow values

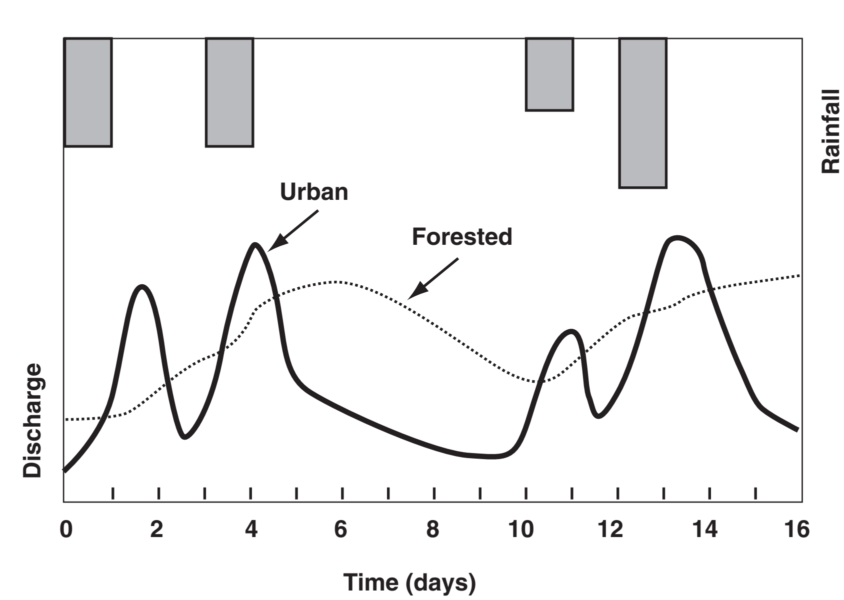


Table 1. Potential hydrologic effects associated with land and water use

Land Use	Land Use Practice	Hydrologic Component Affected	Potential Hydrologic Effects
Forestry	Timber harvest	Peak flow	Increased peak flows due to reduction in evapotranspiration and interception as well as more accumulation and melt of snowpack. Diminished impact as regrowth occurs even though damage to the channels may persist.
		Low flow	Increased low flows due to reduction in evapotranspiration and interception.
	Roads and harvest practices	Peak flow	Rerouted subsurface flows to surface runoff through roadside drainage ditches. Compaction of soil causes increased runoff and decreased infiltration. Logging practices such as skid trails contribute to the same effect.
		Annual yield	Increased water yield due to more accumulation of snowpack in open areas and reduction in evapotranspiration and interception. Most of increase occurs during wet part of the year.
Agriculture/ rangeland	Land drainage through ditching	Peak flow	Increased timing of storm runoff as surface flow moves more quickly to stream.
		Low flow	Lowered water table. Reduced groundwater recharge.
	Draining wetlands	Peak flow	Increased timing of storm runoff as surface flow moves more quickly to stream.
		Low flow	Lowered water table. Reduced groundwater recharge.
	Crop production	Low flow	Altered rates of transpiration affects runoff.
	Cattle grazing	Peak flow	Increased timing of storm runoff due to compaction of soils. Reduced infiltration.
Urban	Increase in impervious surfaces	Peak flow	Reduced infiltration. Surface flow moves more quickly to stream, causing peak to occur earlier and to be larger. Increased magnitude and volume of peak. Can cause bank erosion, channel widening, downward incision, and disconnection from floodplain.
		Low flow	Reduced surface storage and groundwater recharge, resulting in reduced baseflow.
	Use of stormwater facilities	Peak flow	Increased timing of runoff through increased velocity due to lower friction in pipes and ditches. Surface flow moves more quickly to stream via pipes and ditches, causing peak to occur earlier and to be larger. Increased total volume.
Water control structures	Dams and diversions	Peak flow	Reduced magnitude and frequency of high flows. Can cause channel narrowing downstream of dam. Capture of sediment behind the dam can result in downstream channel erosion and bed armoring.
	Levees and channelization	Peak flow routing	Reduced overbank flows. Isolation of the stream from its floodplain. Channel constriction can cause downcutting.
Water use	Surface water diversions	Low flow	Depleted streamflow by consumptive use. Streamflow depleted between point of withdrawal and point(s) of return.
	Groundwater pumping	Low flow	Lowered water table. If hydraulically connected, can cause streambank erosion and channel downcutting after loss of bank vegetation.
	Return flow	Low flow	Altered timing of groundwater/surface water interaction.

problems and to determine the magnitude of impacts. Outlining a detailed assessment process that relies on hydrologic techniques is beyond the scope of this document; however, general guidance for more extensive analyses is provided in the "Level 2 Assessment" section.

Step 1. Summarize land uses

Inspect the land use map from the Scoping process and identify the land uses present in each sub-basin. Validate the boundaries around the mapped land uses using aerial photos, orthophotos, or topographic maps and correct any inaccurate boundaries. Use this corrected land use map to determine the area (acres or mi^2) of forestry, agriculture, rangeland, urban, rural residential, and other land uses in each sub-basin. The areas in each land use can be determined using GIS, calculated using a planimeter, or estimated using the rectangular grid method. Identify the location of structural features on the map, and identify the point of diversion for each significant water use.

Enter the area estimated for each land use in each sub-basin into a table similar to Figure 7.

Figure 7. Sample table format for summarizing land use data

	Land use categories (% of watershed area)					
Sub-basin name	Forestry	Agriculture	Rangeland	Urban	Rural residential	Other
Entire watershed						

Step 2. Screen for potential forestry issues

If commercial forestry is a land use activity in the watershed, then the existing condition of the forest stands in the watershed will need to be assessed. Further investigation will

Vegetation

be needed if the canopy cover of the current forest stand is substantially different from its historical condition. In addition, extensive harvesting within the last few decades may have substantially impacted the hydrology. Confer with the Vegetation analyst to obtain work products and general information on the changes in forest canopy over time. Consult with agency hydrologists or foresters as needed to determine whether regional criteria for harvest management are available or whether there are regional forestry issues that need to be addressed. For instance, much of the timber harvest in the southeastern United States comes from lands occupied by a high percentage of forested wetlands. Impacts of timber harvest on hydrology in this region should specifically address wetlands.

For sub-basins in which commercial forestry raises concern, enter a “Yes” on Form H2. Further investigation may not be warranted if forestry occupies only a small portion of a sub-basin or the vegetative cover condition has not changed substantially; in this case, a “No” may be the appropriate response on Form H2. For sub-basins in which no commercial forestry occurs, enter an “N/A” on Form H2.

Step 3. Screen for potential agriculture or rangeland issues

If agriculture activities or rangeland management occurs in a sub-basin, several questions regarding soil type and agricultural practices will need to be addressed. The impact of agriculture on hydrology is dependent on specific practices such as the type of cover and management treatments, as well as the characteristics of the soil being farmed (Box 13). The infiltration rates of undisturbed soils vary widely. Agriculture has a greater effect on runoff in areas where soils have a high infiltration rate than in areas where soils are relatively impermeable in their natural state (USDA Soil Conservation Service [SCS]1986). Impacts associated with the utilization of rangelands can be assessed in a manner similar to that used for agricultural lands. In addition, cattle grazing on sparsely forested lands can have similar impacts and should be considered under this heading.

Box 13. Example of a regional agriculture issue—peat mining in North Carolina

A study on the Coastal Plain of North Carolina (Gregory et al. 1984) found the following hydrologic impacts associated with peat mining:

- Greater volume, duration, and peak flow of storm discharge from the field ditches on the mining sites than from sites with natural vegetation.
- Quicker overland flow to the ditches on the mining site due to reduced infiltration associated with grading the surface.
- Lower baseflows in the ditches draining the mined sites.

Erosion

The USDA has characterized and mapped the soils for most areas across the United States. Other agencies, such as state land managers and the USFS, are also sources of soil information. As part of the mapping process, soils are classified into one of four hydrologic soil groups (Table 2), primarily as a function of their minimum infiltration rate on wetted bare soil. Confer with the NRCS specialist nearest the watershed to locate soil group information, typical agricultural practices in the watershed, and any regionally specific crops.

Use the percentage of the sub-basin in agriculture, knowledge of associated soil groups, and typical agricultural practices to help determine whether agricultural concerns exist. Enter a "Yes," "No," or "N/A" response on Form H2 for each sub-basin.

Table 2. Hydrologic soil group classification

Hydrologic soil group	Characteristics of soils	Minimum infiltration rate (mm/hr)
Low Runoff Potential A	High infiltration rates even when thoroughly wetted. Deep, well drained sands or gravels with a high rate of water transmission. Sand, loamy sand, or sandy loam.	8 - 12
B	Moderate infiltration rates when thoroughly wetted. Moderately deep to deep, moderately well to well drained, moderately fine to moderately coarse textures. Silt loam or loam.	4 - 8
C	Slow infiltration rates when thoroughly wetted. Usually has a layer that impedes downward movement of water or has moderately fine to fine textured soils. Sandy clay loam.	1 - 4
D High Runoff Potential	Very low infiltration rate when thoroughly wetted; chiefly clay soils with a high swelling potential; soils with a high permanent water table; soils with a clay layer near the surface; shallow soils over near impervious materials. Clay loam, silty clay loam, sandy clay, silty clay, or clay.	0 - 1

SCS (1986)

Step 4. Screen for potential urban, suburban, or rural residential issues

For sub-basins with urban, suburban, or rural residential development, the screening process will rely on estimating the impervious area as the basis for determining potential hydrologic impacts. Impervious surfaces are those that prevent or inhibit the natural infiltration process, such as roads, parking lots, and roof tops. Table 3 displays the average percentage impervious area associated with various types of development. For each sub-basin, use the land use map and aerial photos to estimate the area occupied by the most common types of development. Multiply this area by the average impervious area percentage from Table 3 to obtain an estimate of the sub-basin total impervious area (TIA). If it is not possible to identify the areas of development types, a TIA estimate can be made based on road density (Box 14).

Table 3. Average area of impervious surfaces, urban and residential development

Type of land development	Average impervious area (%)
Urban Districts:	
Commercial and business	85
Industrial	72
Residential Districts by Average Lot Size:	
1/8 acre or less (town houses)	65
1/4 acre	38
1/3 acre	30
1/2 acre	25
1 acre	20
2 acre	12

SCS (1986)

Optional Task: Compute the weighted average percentage impervious value for all development types in the sub-basin.

Box 14. Using road density to estimate impervious area

If difficulties arise in estimating impervious areas, the extent of development can often be expressed in terms of road density. May et al. (1997) established a relationship between watershed urbanization (percentage TIA) and sub-basin road density (mi/mi^2) that can be used as a surrogate for percentage impervious surfaces in the Pacific Northwest. In urbanized areas of the Pacific Northwest when road densities equal or exceed 5.5 mi/mi^2, TIA probably exceeds 10 percent.

Concern for potential urban-related hydrologic issues should arise for each sub-basin that exceeds a regionally appropriate percentage impervious area threshold. For Puget Sound Lowland streams in Washington, May et al. (1997) recommend that impervious area be limited (< 5-10 percent TIA) to maintain stream quality, unless extensive riparian buffers are in place. Consult agency hydrologists or research in the vicinity of the watershed to develop a threshold of concern applicable to the watershed. Schueler's (1994) review of 18 urban stream studies revealed that a sharp decline in species diversity was often associated with 10 percent or greater TIA.

Based on the estimated total impervious area in the watershed, designate sub-basins in which urban use is of concern by entering a "Yes" or "No" response on Form H2.

Step 5. Screen for potential water control structure issues

For sub-basins with man-made water control structures and storage facilities, determine the portion of the watershed influenced by each structure. Each reservoir has its own operating scheme and, therefore, will require more detailed hydrologic investigations, often including release schedules, reservoir routing, etc. If there is a sizable reservoir in the watershed, further technical analyses will be required for the portion of the watershed below the dam, but some of the steps can be completed for the land uses present in the portion of the watershed above the dam. Consult with hydrologists at the Bureau of Reclamation, USACE, public utilities, or local reservoir operators to obtain information about the operating scheme.

Channel

Other types of structures, such as dikes, levees, or channelization, can affect the hydrologic function of a watershed because they modify channel configuration. Confer with the Channel analyst to assess reaches of concern.

In consultation with agency hydrologists and using data collected in the characterization section, determine the extent to which the structures may be altering the hydrology of the watershed. Sub-basins in which structures may cause changes to the hydrology will require further study and should receive a "Yes" response on Form H2.

Step 6. Screen for potential water use issues

For sub-basins in which water is being withdrawn from either surface or groundwater, comparisons of stream flow to water use will be necessary. Determine the time of year when water use is the highest. If possible, compile estimates of monthly water use based on information collected in Step 7 of Section 1.

In many regions throughout the country, high demand for water occurs during the low flow season. The reduction of streamflow due to water use is of particular concern during the low flow season. Consider whether a pattern emerges when comparing monthly streamflow to monthly water demand.

Further investigation of water use and allocation issues may be warranted if consumptive use is high in one or more sub-basins, particularly if the low flow period coincides with times of high water use. In addition, while the impact to low flows of a surface water withdrawal is fairly straightforward to account for and immediately felt, the impact of groundwater withdrawals on nearby streams is not as easily understood. Characterizing the groundwater/surface water interactions (termed hydraulic continuity) may be necessary in areas where water use and water supply requirements are competing with fisheries protection measures, such as enforcing minimum in-stream flows.

In consultation with agency hydrologists and using data collected in the characterization section, determine the extent to which water use is depleting streamflow. Sub-basins in which water use may be a concern will require further study and should receive a "Yes" response on Form H2. Sub-basins with minimal water use may not need further study.

Step 7. Produce Hydrology report

Generate a brief report summarizing the information gathered. The report should feature the tables, graphs, and forms produced as well as a narrative describing the hydrologic and climatic character of the watershed and the potential land and water use impacts.

Level 2 Assessment

Once the initial watershed characterization and the screening for potential impacts have been completed, the focus of future assessment efforts should be reasonably clear. This section provides a general discussion of available options for Level 2 characterization and analyses. The Level 2 methods and specific tools required will differ for each watershed depending on issues revealed during the Level 1 assessment. Level 2 analyses will be more technical and extend the level of detail beyond that used in Level 1 (see Hydrology Module Reference Table).

Level 2 Characterization

Streamflow patterns

The methods for a Level 2 characterization of streamflow will be a function of available data and Level 1 products. For Level 2 analyses, determination of streamflow for each sub-basin will be necessary to assess the patterns and trends over time. Level 2 methods may include the following:

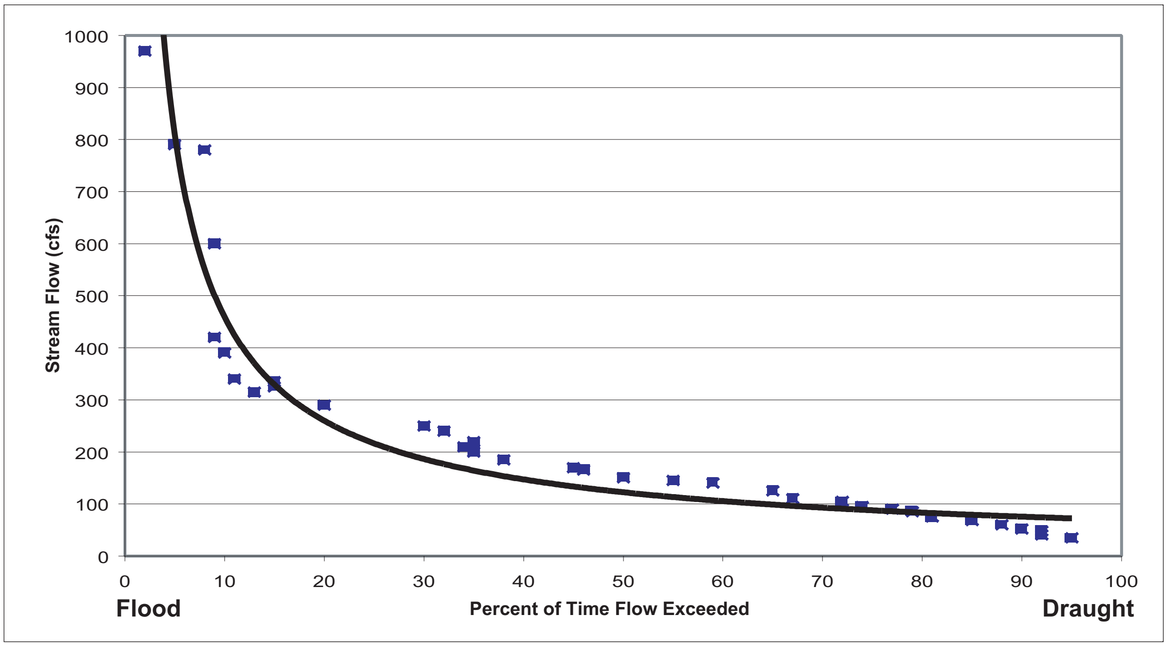
- Applying streamflow statistics from one gage location to another point in the watershed (e.g., applying unit runoff from an upstream point to the mouth of a watershed).
- Using regional regression equations for watersheds that are ungaged and have no streamflow records.
- Using correlation techniques for stations with short periods of record and extending them using long-term data from another gage that drains a hydrologically similar watershed.

Statistical information on extreme events generated through flood frequency analyses (e.g., log pearson type III), low flow frequency analyses, or $7Q^{10}$s can provide perspective on the range of expected extreme flows. Frequency analyses can be performed using annual peak flow series data or partial series data.

Aquatic Life
Water Quality

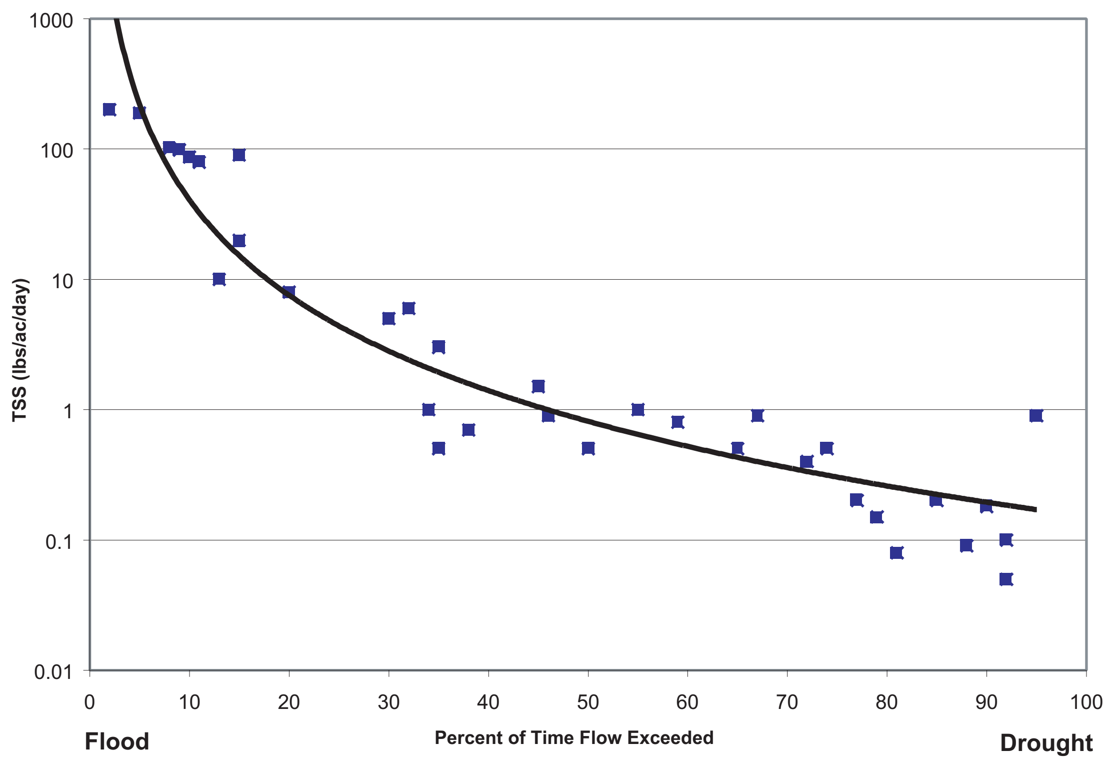
Flow duration curves provide an excellent way to represent streamflow data to better target pollution sources and effective management strategies. A flow duration curve is the cumulative frequency of stream flow without regard to the chronology of occurrence (Leopold 1994). Flow duration curves represent the percentage of time a given value of stream flow will be exceeded (Figure 8). Thus, the highest streamflows on record (i.e., flood conditions) will correspond to the lowest percentages, whereas the lowest streamflows (i.e., drought conditions) will correspond to the highest percentages. Duration curves generally reflect average daily flows but may also represent weekly or monthly flows.

Figure 8. A hypothetical example of a flow duration curve based on mean daily stream flow.



Since nonpoint source pollution is often driven by runoff events, watershed management plans or TMDL development may need to target different factors across the range of flow conditions to restore water quality (Cleland 2002). Flow duration curves can help to diagnose the source of problems and target specific activities or areas for improvement. For example, if exceedence of water quality criteria occur at low flows, point sources of pollution are likely to be targeted, whereas if exceedence occurs at high flows, nonpoint sources and land management activities may need to be targeted. Figure 9 provides a hypothetical example showing higher suspended sediment values at high flows, potentially indicating a problem with non-point sources of sediment or bank erosion. Flow duration curves may also be useful in evaluating pollutant load trading to ensure that the timing and amount of pollutant load exchange provides adequate water quality protection. Flow duration curves may be particularly helpful in providing insights for the Aquatic Life and Water Quality modules."

Figure 9. A hypothetical example relating the annual flow duration curve with suspended sediment pollutant load.



Precipitation patterns and other climate data

Data from additional precipitation and snow stations can help to further characterize the precipitation patterns and their influences on the hydrologic regime. Data from more than one station along with NOAA maps or PRISM (Parameter-elevation Regressions on Independent Slopes Model) maps developed by Oregon Climate Service (**http://www.ocs.orst.edu/**) can be used to determine precipitation distribution throughout each sub-basin. Multiple station data can also be useful for evaluating the impacts of elevation and aspect on hydrologic processes such as rain, snow, or a combination thereof. Precipitation frequency analyses reveal the magnitude and frequency of extreme precipitation events. Level 2 analyses typically rely on additional climate data such as temperature, wind, and evaporation data.

Trend analyses

Level 2 analyses may involve detecting trends in the streamflow or climate parameters. A trend can be defined as a systematic increase or decrease over time of one particular parameter (e.g., streamflow or temperature). Several options for detecting underlying trends in time-series data sets are available. The first step is often to perform some type of smoothing technique such as a moving average to reduce the effects of non-systematic variation in flows. Moving averages can be calculated for different time periods (e.g., 5-year or 10-year moving averages) depending on the availability of data. The Mann-Kendall nonparametric test can be used to discern monotonically increasing or decreasing trends in streamflow or precipitation data (Maidment 1992).

A double mass analysis is useful for the detection of changes in relationships between two monitoring stations. This may become important if the location of a station has changed over its period of record or if a change in land use practices has occurred around one station but not the other.

Groundwater and other natural storage

Level 2 analyses may require further definition of groundwater issues. The average daily hydrograph of surface water can be used to evaluate baseflow characteristics that are usually supplied by groundwater discharge. Groundwater/surface water interactions can be qualitatively addressed by examining a graph of the logarithm of discharge versus time. The slope of the recession on this graph indicates the role of groundwater in sustaining baseflows. The groundwater component of streamflow can also be evaluated using a computer-based hydrograph separation technique (such as HYSEP [Sloto and Crouse 1996]) or summary statistics from the daily minimum streamflow records. Surficial aquifers can be delineated and mapped based on comparisons of physical properties such as depth to groundwater, surficial geology, soil properties, and the presence or absence of near-surface aquitards (geological strata that limit groundwater seepage).

Monthly or daily tracking of hydrologic components in a water budget may provide more information on the state of the water table fluxes, the lags between storage components, and ultimately, the impact of groundwater and other storage on streamflow. This can be accomplished using a spreadsheet or a watershed hydrologic model such as BASIN (see Table 4 in the "Land Use" section, below).

Runoff generating processes

The compilation of daily streamflow and climate data for the duration of typical storms can be useful for further characterizing the watershed's runoff response. For instance, in areas where rainfall duration has a large influence on producing watershed runoff, daily precipitation values for several days prior to and including the day of the annual peak flows will be helpful in detecting patterns. In other areas where rainfall intensity may strongly influence the generation of runoff, collection of data on the rates of rainfall throughout a day may offer insight into watershed processes.

In still other areas, runoff may result primarily from the combination of rainfall and water resulting from snowmelt during the storm. Collection of temperature and snowpack data prior to and during the time of annual peak flow events will help to determine the propensity for snowpack to contribute melt water during storms; these storms are referred to as rain-on-snow events.

Level 2 Analysis

Water control structures

Level 2 analyses of water control structures will include techniques tailored to the physical setting and operating scheme of each structure. Reservoir routing, watershed modeling, and other techniques may be necessary to assess impacts of different operating rules on downstream flows or to deregulate streamflow records. Supporting statistics can be generated to respond to specific inquiries. For example, the Kootenai Tribe of Idaho posed the following question: Has the dam changed the season in which floods typically occur (Box 15)? Other questions may arise regarding changes to the magnitude of flooding. For larger, multi-purpose reservoirs, operators typically employ continuous hydrologic models to forecast inflows, estimate lake levels, and schedule outflows. These models have been calibrated to the watershed and may provide a useful tool for the Level 2 assessment.

In watersheds with numerous small diversion structures, water use may become the focus such that Level 2 analyses will need to include quantification of the cumulative impacts numerous withdrawals may have on seasonal low flows.

Water use

Box 15. Analysis of dam effects on the Kootenai River, Idaho

The Kootenai Tribe of Idaho recently completed a Kootenai River Watershed Assessment (Sasich et al. 1999). As part of this assessment, impacts of a dam were investigated. The table below summarizes the number of peak flood events in the pre-dam period compared to the post-dam period. The analysis was completed for three time categories that represent critical life stages for the aquatic species of concern in the watershed. This investigation demonstrates that the temporal sequence of floods has been substantially altered by the dam operations; a higher percentage of floods has occurred from November to March in the post-dam period than in the pre-dam period. Also, more floods occurred in the pre-dam period between April 15 and June 30 than after the dam was constructed.

Peak Floods at Leonia Gage (includes annual and partial series data)

	Pre-dam (water year 1929-71)		**Post-dam** (water year 1972-98)	
Time period	**Number of floods**	**% of total**	**Number of floods**	**% of total**
April 15 - June 30	90	92	9	32
July - October	7	7	7	25
November - March	1	1	12	43

A relatively easy way to initially characterize water use in a watershed is to tabulate the designated beneficial uses for both the surface and groundwater rights that are on file with the state agency responsible for water law administration. Water rights have different entitlements across the country depending on the water law in effect (Box 16). Understanding the implications of the applicable water law will be necessary for completing a Level 2 analysis.

Water rights, diversions, and use can be tracked by employing a water allocation model or a spreadsheet depending on the complexity of the situation. A water allocation model accounts for natural inflows, diversions, consumptive use (depletions), and return flows based on the state water laws. Output can provide the physical and legal availability of water for the reaches and time periods designated. A water allocation model tracks human uses of water while a hydrologic water

Box 16. Water law and water rights

Currently, 29 eastern states utilize the riparian rights system, in which a landowner is entitled to the use of the water bordering his or her property. Water law in the western states is based on the prior appropriation doctrine or "first in time, first in right." Approximately 10 states use a hybrid system that combines attributes from the riparian rights and the prior appropriation doctrine. The prior appropriation doctrine entitles the most senior appropriators to divert water prior to any water rights holders with a later date (junior). Indian reservations, national forests, national parks, and BLM lands are all examples of federal reservations. These entities maintain federal reserved rights for the purposes for which the reservation was established and the priority date of the water right is the date the reservation was established.

balance model simulates the natural watershed processes that depend on climate inputs (precipitation, temperature, wind, solar radiation, etc.) and the physical parameters such as soil type and condition, geologic and topographic features, vegetative cover, and channel location.

Water allocation calculations can track the inflows and outflows of water, spatially and temporally. The spatial scale at which to operate a model must be carefully chosen. Calculating water allocation on an annual basis at the mouth of a river may show plenty of water. However, calculation at several locations in the same watershed on a monthly or biweekly schedule may reveal problems that a more aggregated water budget may mask.

In many regions, instream rights have become common as a means of protecting the biological resources. In-stream flows have been established and, in some cases, a water right has been awarded under the state agency in charge. In some states, in-stream flows are synonymous with minimum flows; however, many contend that in-stream flows should be set at a reasonable amount of flow to sustain biological resources, which is not the same as a minimum flow. Comparison of instream flow rights to the minimum flow records at several points in a watershed can help identify reaches of concern for fisheries and other biological resources.

Actual water use does not always measure up to the amount designated on water rights certificates. In some cases, illegal uses of water occur, abandoned rights exist, or certain rights are not used to their full extent. Collection of actual water use data can add more detail to a study aimed at the identification of reaches of concern. State departments of health, conservation districts, and agricultural extension offices are good sources of actual water use data as are records from the individual water purveyors in a watershed.

Investigations that address hydraulic continuity will be essential in some watersheds. The formulation of specific technical questions along with knowledge of the available data will assist in determining the approach for further hydrogeologic investigations. In some watersheds, the timing of potential surface water capture by groundwater may be important, while in other watersheds the analyst may only be interested in a spatial analysis that defines the zone of hydraulic connectivity to a certain surface water source. In areas where extensive groundwater data are available, a complex numerical model, such as ModFlow, can be employed to determine the magnitude, distribution, and timing of hydraulic effects.

Land use

Although it is fairly straightforward to identify the potential for a land use problem, attempting to quantitatively assess the magnitude of the problem or the hydrologic change is complex. The impacts of land uses on hydrology will vary from region to region and even from watershed to watershed. So too will the selection of appropriate analysis tools. Selection from the many options of technical tools will depend upon the available input data and the specific questions that need to be addressed. The available tools range in complexity from empirical equations to storm hydrograph methods to mechanistic hydrologic models operated on a daily time step or even finer detail. Table 4 identifies several techniques that may be useful, but it by no means constitutes a definitive list.

Continuous models can be applied at the watershed scale and may be necessary to assess cumulative impacts of several land uses in a watershed. For assessing urban impact from small, developed areas, unit hydrographs can be used (e.g., Santa Barbara Unit Hydrograph, Colorado Unit Hydrograph). Analysts assessing urban impacts may need the ability to route stormwater through drainage networks, while analyses of forestry impacts will need to address changes in forest cover as well as the differential accumulation and melt of snow. Snowmelt models may also be necessary in rangelands as snowmelt can often be an important element in many rangeland areas. In addition, the impact of the road network on the routing of surface water in rural and forest settings should be addressed in Level 2 analyses.

The single event hydrograph model TR55, based on the SCS runoff curve number technique, is probably the most commonly used tool applied to the agricultural setting. The curve number technique was originally developed for predicting changes in storm runoff volume associated with changing land management practices. More complex tools include BASIN, developed by the Bureau of Reclamation, Nebraska-Kansas Office. The BASIN program computes irrigation farm delivery requirements, project diversion requirements, groundwater diversion recharge, or watershed outflow, depending on how the model is configured. In addition, BASIN will compute streamflow depletions or net change in groundwater recharge due to a change in cropping patterns or irrigated acreage.

Keep in mind that many of the hydrologic tools and models suggested here (Table 4) are capable of evaluating impacts from several land uses while others perform well only for specific land uses. For example, TR55 was developed using data from small rural/agricultural watersheds and has proved useful in rural catchments for comparison of runoff under differing vegetative cover conditions. TR55 has not performed as well in steep forested watersheds where subsurface pathways are dominant (Fedora 1987). The applicability of many of the tools will be limited to the region in which they were developed, while others will be useable across the country.

Table 4. Examples of hydrologic tools for Level 2

Land use	Examples of hydrologic models or technical tools and contact entity
Forestry	• Washington State Watershed Analysis Methodology - Washington Forest Practices Board (WFPB 1997) • DRAINMOD/DRAINLOB - North Carolina State University • Antecedent Precipitation Index (API) - Oregon State University • DHSVM (Distributed Hydrologic Soils Vegetation Model) - Dennis Lettenmaier, University of Washington, Seattle, Washington
Agriculture/rangeland	• TR55 - NRCS • DRAINMOD - North Carolina State University • Basin - Bureau of Reclamation • Simulating Production and Utilization of Range Land (SPUR) - USDA • HFAM (Hydrologic Forecasting & Analysis Model) - Norm Crawford, HYDROCOMP, Inc., Palo Alto, California
Urban/rural residential	• Hydrologic Simulation Program Fortran (HSPF) - EPA • HFAM (Hydrologic Forecasting & Analysis Model) - Norm Crawford, HYDROCOMP, Inc., Palo Alto, California • Water Resources Evaluation of Nonpoint Silvicultural Sources Model (WRENSS) - USFS • PRMS (Precipitation Runoff Modeling System) - George Leavesly, USGS, Denver, Colorado • Regionalized Synthetic Unit Hydrograph methods (e.g. Santa Barbara, Colorado unit hydrograph) • Stormwater runoff network models (e.g., KYPIPE, WaterWorks)

References

Atkins, J. B., C. A. Journey, and J. S. Clarke. 1996. Estimation of ground-water discharge to streams in the Central Savannah River Basin of Georgia and South Carolina. U.S. Geological Survey, Water Resource Investigations Report 96-4179, Atlanta, Georgia.

Bachman, L. J. 1997. Groundwater nitrate loads in non-tidal tributaries of Chesapeake Bay 1972-92. American Geophysical Union, EOS Transactions 78(46).

Bicknell, B. R., J. C. Imhoff, J. L. Kittle, Jr., A. S. Donigian, Jr., and R. C. Johanson. 1997. Hydrological simulation program-Fortran, user's manual for version 11. U.S. Environmental Protection Agency, National Exposure Research Laboratory, EPA/600/R-97/080, Athens, Georgia.

Black, P. E. 1991. Watershed hydrology. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Branson, F. A., G. F. Gifford, K. G. Renard, and R. F. Hadley. 1981. Rangeland hydrology. Range Science Series No. 1, second edition. Kendall/Hunt Publishing Co., Dubuque, Iowa.

Brown, D. S., and J. T. Patton. 1995. Recharge to and discharge from the Edwards Aquifer in the San Antonio area, Texas. U.S. Geological Survey, Open-File Report 96-181, San Antonio, Texas.

Cleland, B. 2002. TMDL development from the "bottom up" - Part II: Using duration curves to connect the pieces. August 15, 2002. American Clean Water Foundation, Washington, D.C.

Dunne, T., and L. Leopold. 1978. Water in environmental planning. W.H. Freeman and Company, San Francisco, California.

Fedora, M. A. 1987. Simulation of storm runoff in the Oregon Coast Range. U.S. Department of Interior Bureau of Land Management, Technical Note 378, Denver, Colorado

Gregory, J. D., R. W. Skaggs, R. G. Broadhead, R. H. Culbreath, J. R. Bailey, and T. L. Foutz. 1984. Hydrologic and water quality impacts of peat mining in North Carolina. The Water Resources Research Institute, Report No. 214, North Carolina State University.

Heath. 1984 Ground-water regions of the United States. U.S. Geological Survey, Water-Supply Paper 2242, Reston, Virginia.

Holtschlag, D. J., and J. R. Nicolas. 1998. Indirect ground water discharge to the Great Lakes. U.S. Geological Survey, Open-File Report 98-579.

Hoos, A. B. 1990. Recharge rates and aquifer hydraulic characteristics for selected drainage basins in middle and east Tennessee. U.S. Geological Survey, Water Resources Investigation Report 90-4015, Nashville, Tennessee.

Kattelmann, R. C., N. H. Berg, and R. Rector. 1983. The potential for increasing streamflow from Sierra Nevada watersheds. Water Resources Bulletin 19(3):395.

Langland, M. J., P. L. Lietman, and S. Hoffman. 1995. Synthesis of nutrient and sediment data for watersheds within the Chesapeake Bay drainage basin. U.S. Geological Survey, Water Resources Investigations Report 95-4233, Denver, Colorado.

Leavesley, G. H., R. W. Lichty, B. M. Troutman, and L. G. Saindon. 1983. Precipitation-runoff modeling system: user's manual. U.S. Geological Survey, Water-Resources Investigations Report 83-4238, Denver, Colorado.

Leopold, L. B. 1968. Hydrology for urban land planning: a guidebook on the hydrologic effects of urban land use. U.S. Geological Survey, Circular 554, Washington, D.C.

Leopold, L.B. 1994. A View of the River. Harvard University Press. Cambridge, MA.

Maidment, D. R. 1992. Handbook of hydrology. McGraw-Hill, New York, New York.

May, C. W., E. B. Welch, R. R. Horner, J. R. Karr, and B. W. Mar. 1997. Quality indices for urbanization effects in Puget Sound lowland streams. Final report prepared for Washington Department of Ecology, Centennial Clean Water Fund Grant, Water Resources Series, Technical Report No. 154, Olympia, Washington.

May, C. W., R. R. Horner, J. Karr, B. W. Mar, and E. B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound Lowland ecoregion. Watershed Protection Techniques 2(4):483-493.

McCammon, B., J. Rector, and K. Gebhardt. 1998. A framework for analyzing the hydrologic condition of watersheds. U.S. Department of Agriculture Forest Service and U.S. Department of the Interior Bureau of Land Management, BLM Technical Note 405.

Miller, J. F., R. H. Frederick, and R. J. Tracey. 1973. Precipitation-frequency atlas of the western United States, Volume X: Oregon. National Oceanic and Atmospheric Administration, NOAA Atlas 2, Silver Spring, Maryland.

Otradovsky, F. 1981. BASIN user's manual. North Platte River Projects Office, Mills, Wyoming.

Poff, L. N., J. D. Allan, M. B. Bain, J. J. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997 The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47(11):769-784.

Robison, E. G. 1991. Water availability for Oregon's rivers and streams, Volume 1: Overview. Oregon Water Resources Department, Hydrology Report #1.

Ross and Associates Environmental Consulting, Ltd. 1998. Recommended technical methods for evaluating the effects of ground-water withdrawals on surface water quantity. Draft report of the Technical Advisory Committee on the Capture of Surface Water by Wells.

Rutledge, A. T., and T. O. Mesko. 1996. Estimated hydrologic characteristics of shallow aquifer systems in the Valley and Ridge, the Blue Ridge, and the Piedmont physiographic provinces based on analysis of streamflow recession and base-flow. U.S. Geological Survey, Professional Paper 1422-B, Washington, D.C.

Sasich, J., P. Olsen, and J. Smith. 1999. Kootenai River watershed assessment, final report. Prepared for the Kootenai Tribe of Idaho.

Satterland, D. R., and P. W. Adams. 1992. Wildland watershed management. John Wiley and Sons, Inc., New York, New York.

Schueler, T. 1994. The importance of imperviousness. Watershed protection techniques 1(3):100-111.

Sinclair, K. A., and C. F. Pitz. 1999. Estimated baseflow characteristics of selected Washington rivers and streams. Water Supply Bulletin No. 60, Washington Department of Ecology, Publication No. 99-327, Olympia, Washington.

Skaggs, R. W. 1990. DRAINMOD user's manual. North Carolina State University, Raleigh, North Carolina.

Sloto, R. A., and M. Y. Crouse. 1996. HYSEP: A computer program for streamflow hydrograph separation and analysis. U.S. Geological Survey, Water Resources Investigation Report 96-4040, Lemoyne, Pennsylvania.

Sun, G., S. G. McNulty, J. P. Shepard, D. M. Amatya, H. Riekerk, N. B. Comerford, R.W. Skaggs, and L. Swift Jr. 1999. Effects of timber management on wetland hydrology in the eastern United States. National Council of the Paper Industry for Air and Stream Improvement, Forested Wetlands Research, Gainesville, Florida.

U.S. Department of Agriculture Soil Conservation Service (SCS). 1985. National engineering handbook, Section 4, Hydrology. SCS, Washington, D.C.

U.S. Department of Agriculture Soil Conservation Service (SCS). 1986. Urban hydrology for small watersheds. SCS, Technical Release 55, Washington, D.C.

U.S. Geological Survey (USGS). 1979. Magnitude and frequency of floods in western

Form H1. General watershed characteristics

Watershed Name: ___________________________

Sub-basin information:

Sub-basin name	Sub-basin area (mi^2)	Mean elevation (ft)	Minimum elevation (ft)	Maximum elevation (ft)	Mean annual precipitation (inches)
Total watershed					

- Mean annual precipitation can be estimated from the Mean Annual Precipitation Map (from NOAA)
- Minimum and maximum elevations can be estimated from the base map or USGS quad maps.

Describe the type and extent of natural storage (lakes, wetlands, etc.) in the watershed.

What watershed changes have occurred that will affect streamflows (i.e., dams, major diversions for urban water supply, irrigation diversions, industrial use, etc.)?

Information on stream gages in watershed: (Note: if more than one gage, fill out additional forms.)

Gage #:
Gage name :
Gage elevation:
Drainage area to gage:
Storage or regulation upstream of gage (yes or no)? If yes, describe on back of sheet

Form H2. Summary of hydrologic issues by sub-basin

Sub-basin name	Potential forestry issue?	Potential agriculture or rangeland issue?	Potential urban or residential development issue?	Potential water control structure issue?	Potential water use issue?	Describe the rationale behind the responses
Entire watershed						